Naval Surface Warfare Center
Carderock Division
West Bethesda, MD 20817-5700

NSWCCD-65-TR–2005/24 October 2005

Survivability, Structures, and Materials Department

Technical Report

Structural Irregularity and Damage Evaluation Routine (SIDER) for Testing of the ½-Scale Corvette Hull Section Subjected to UNDEX Testing

by

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DEPARTMENT OF THE NAVY

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From: Commander, Naval Surface Warfare Center, Carderock Division
To: Chief of Naval Research (ONR 332)

Subj: SIDER NDE INSPECTION OF A ½-SCALE CORVETTE HULL SECTION

Ref: (a) Project Agreement RTP-US-GE-N-95-002

Encl: (1) NSWCCD-65-TR–2005/24, *Structural Irregularity and Damage Evaluation Routine (SIDER) for Testing of the ½-Scale Corvette Hull Section Subjected to UNDEX Testing*

1. Reference (a) requested the Naval Surface Warfare Center, Carderock Division (NSWCCD) to perform SIDER inspections for the glass-reinforced plastic (GRP) hull underwater explosion (UNDEX) test series, conducted at Eckernforde, Germany, from 20 through 29 May 2005. Enclosure (1) describes performance of a SIDER inspection of the entire GRP Hull of a 1/2-scale corvette after each of four underwater explosion (UNDEX) loadings. SIDER was able to identify changes for the entire structure in approximately five hours from beginning (setting up equipment) to end (having plots of where the changes occurred on a planform of the hull). By comparison, conventional ultrasonic inspection of about 1/4 of the starboard side of the hull required approximately two days. The coordination of a preinspection using SIDER to guide where conventional techniques should concentrate their effort would reduce overall inspection time.

2. Comments or questions may be referred to Dr. Roger M. Crane, Code 655; telephone (301) 227-5126; e-mail, Roger.Crane@navy.mil.

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By direction

Subj: SIDER NDE INSPECTION OF A ½-SCALE CORVETTE HULL SECTION

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Enclosure (1)

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14. ABSTRACT

This effort entailed performing Structural Irregularity and Damage Evaluation Routine (SIDER) inspection of the entire GRP Hull of a 1/2-scale corvette mid-ship section after each of three underwater explosion (UNDEX) loadings. The SIDER testing was being used to rapidly interrogate the entire hull structure to identify the areas that had experienced structural degradation that manifested itself in a structural stiffness change. These SIDER results were then compared with the results from a conventional ultrasonic inspection. SIDER is currently being evaluated as a precursor to a rapid conventional non-destructive evaluation (NDE) of large composite structures. The corvette hull provided a platform to determine where conventional NDE inspectors should concentrate their inspections. SIDER was able to identify changes for the entire structure in approximately five hours from beginning (setting up equipment) to end (having plots of where the changes occurred on a planform of the hull). By comparison, conventional ultrasonic inspection of about 1/4 of the starboard side of the hull required approximately 2 days. The coordination of a preinspection using SIDER to guide where conventional techniques should concentrate their effort would reduce overall inspection time and cost.

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The Structures and Composites Division (Code 65) of the Survivability, Structures and Materials Department at the Naval Surface Warfare Center, Carderock Division (NSWCCD), in collaboration with the Wehrtechnische Dienststelle der Bundeswehr für Schiffe und Marinewaffen -WTD71-Bundeswehr Technical Center for Ships and Naval Weapons, Federal Republic of Germany, performed the work described in this report. The work was funded by the Chief of Naval Research (ONR 332) under Project Agreement RTP-US-GE-N-95-002.

Acknowledgements

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Background

The Structural Irregularity and Damage Evaluation Routine (SIDER) is a procedure, which looks at an entire structure and identifies locations where there is variability in structural stiffness. This may be caused by either the variability of the structure itself, or by damage. After a baseline SIDER, changes in the plots can identify locations where the structural variability has changed. These locations can be attributed to damage occurring between the two examinations.

A Seeman Composite Resin Infusion Molding Process (SCRIMP) half-scale composite ship hull section was designed, manufactured and tested under joint United States/Germany project agreement RTP-US-GE-N-95-0002. The hull was subjected to underwater explosions (UNDEX) in the Baltic Sea, approximately 5 miles southeast of Olpenitz, Germany. Four separate UNDEX tests were conducted. A baseline SIDER was conducted prior to the first UNDEX and follow-up SIDER tests were conducted after the 2nd, 3rd and 4th UNDEX tests. SIDER was not conducted after the 1st UNDEX. This report details the results of the SIDER tests.

Diary of Events and Test Matrix

SIDER tests are summarized in Table 1. Times, where given, are for actual data acquisition and exclude travel, setup and breakdown. The times are local times (Germany).

Table 1. Summary of Tests

SIDER Test ID	Event	Date of SIDER data acquisition	Location	Notes
0a	Baseline	Tuesday/Wednesday 3/15/05 and 3/16/05	Kiel	Quiet structure, some instrumentation problems
0b	Baseline	Wednesday 3/16/05	Kiel	Noisy structure
0c	Baseline patch	Thursday 3/17/05	Kiel	Patch to check effect of instrumentation and noise
2	Post 2nd UNDEX	Tuesday 5/24/05 1737-2135	Olpenitz	Test started approx. half-hour after hull was repositioned on jetty. Very windy.
3	Post 3rd UNDEX	Thursday 5/26/05 1432-1806	Olpenitz	Test started approx. half-hour after hull was repositioned on jetty
4	Post 4th UNDEX	Wednesday 7/13/05 0811-1241	Olpenitz	UNDEX test conducted 5/31/05. Quiet structure for SIDER.

The latitude and longitude positions of the two SIDER test locations were:

Kiel: 54°19.4'N 10°09.6'E

Olpenitz: 54°39.8'N 10°01.5'E

These locations, as well as the location of the second UNDEX as logged by GPS, and the location of the main hotel in Eckernforde are shown in Figure 1.

The instrumentation problems during SIDER Test ID#0a were related to poor electrical grounding, causing the operators to get electric shocks from the equipment and a work bench. The problem also caused the equipment to routinely overload and reset itself. Both electrical shocks and resetting continued to happen even when the equipment was externally grounded to a large grounding strap already fastened to the steel ends of the hull section. Initial attempts to isolate the equipment by using a transformer failed. The problem was resolved by purchasing a German extension cable and splicing the plug from it onto the distribution box used for the SIDER equipment.

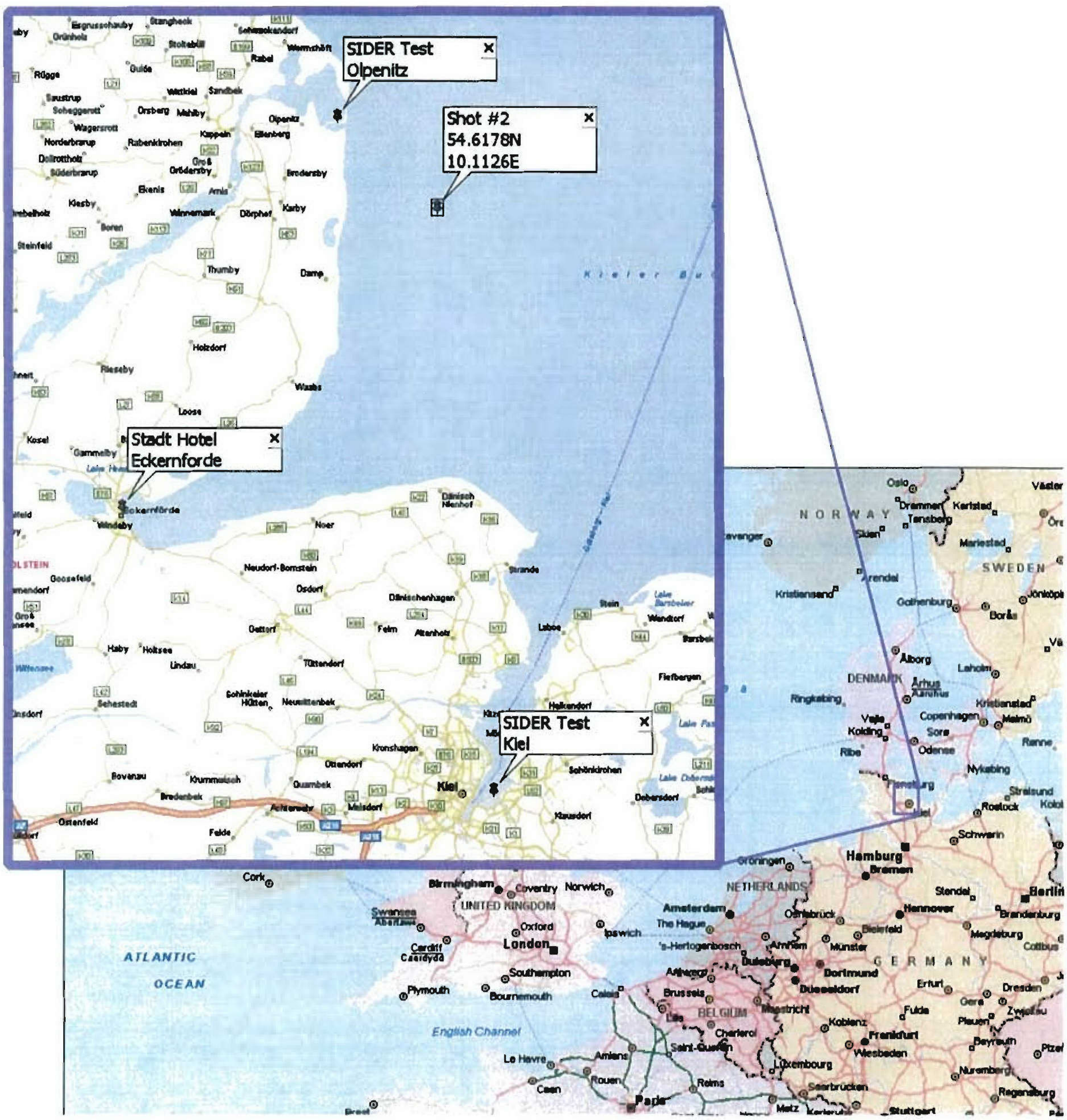

Figure 1. SIDER Test Locations

For SIDER Test ID#0b, several people were moving about inside the hull while they worked on other UNDEX-related equipment. It was decided to continue SIDER testing in order to evaluate the effect of these moving masses and extraneous vibrations on the SIDER test results. The results of this test are described later in this report.

Grid

In order to conduct a SIDER analysis, the structure needs to be marked with a mesh of test points. Previous corvette hull work in 2002 required a uniform one-foot square mesh. Since that date, SIDER has been updated and improved such that it no longer needs a uniform mesh. Thus, for the work reported here, the mesh was changed to coincide more closely with internal stiffener structure. Lines of test points were placed on the outside of the hull, coincident with the internal stiffener tabbing. Additional lines of test points were placed between these tabbing-related lines.

The global origin for the test mesh was chosen to be on the keel, coincident with transverse ship stiffener #4. This is the stiffener across the middle of the hull section. The positive Y-direction was forward. The positive X-direction was directed toward the starboard side, but rotated about the Y-axis so that it was always tangent to the curved surface of the hull. The positive Z-direction formed a right hand axis set with the X- and Y- axes, and was thus always normal to the hull surface. This rotating axis system is demonstrated in Figure 2.

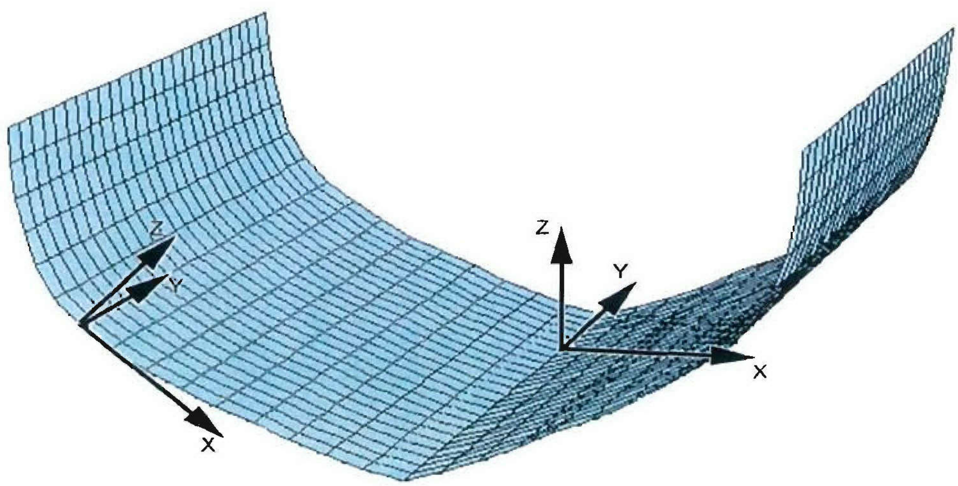

Figure 2. Rotating Axis System

In order to show the SIDER results on paper, the mesh was "unwrapped" such that the X- and Y-axes are planar, as demonstrated in Figure 3.

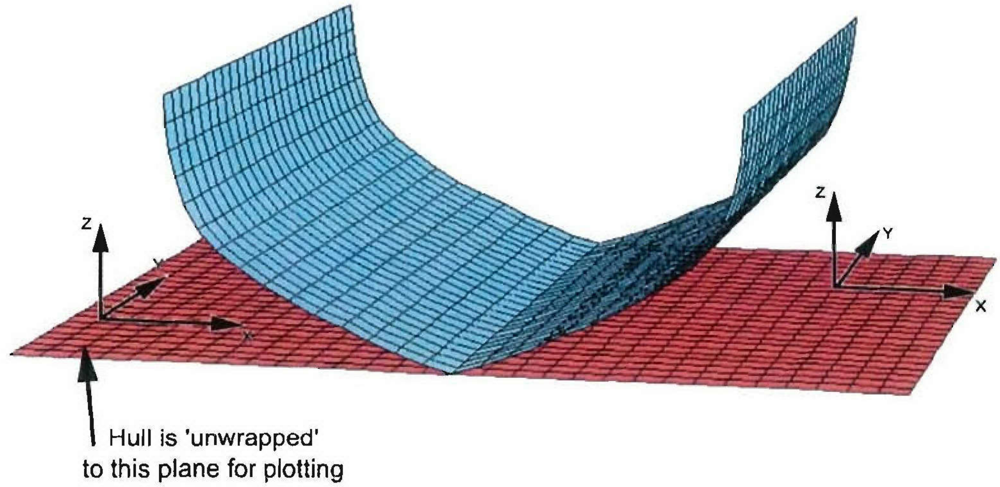

Figure 3. SIDER Results Plotted on the Red Plane

A schematic of the structural details of the hull in planar form is shown in Figure 4. The letters B, C, D, etc show the locations of the longitudinal stiffeners and the numbers 1, 2, 3, etc. show the locations of the transverse stiffeners. These letter and number identifiers are the ones established by NSWC and WTD for all documentation associated with this program. The solid magenta lines indicate the approximate centerlines of the stiffeners. Figure 5 shows the test mesh, with black crosses used for SIDER testing and their locations relative to the stiffeners. There were 1014 individual SIDER test points. For comparison, in the remainder of this report, the white area in the figures shows the area which was visually and ultrasonically tested (VT/UT), with the light green area showing the area that was not subject to VT/UT inspection.

The entire area was SIDER inspected.

Only the white area was VT/UT inspected.

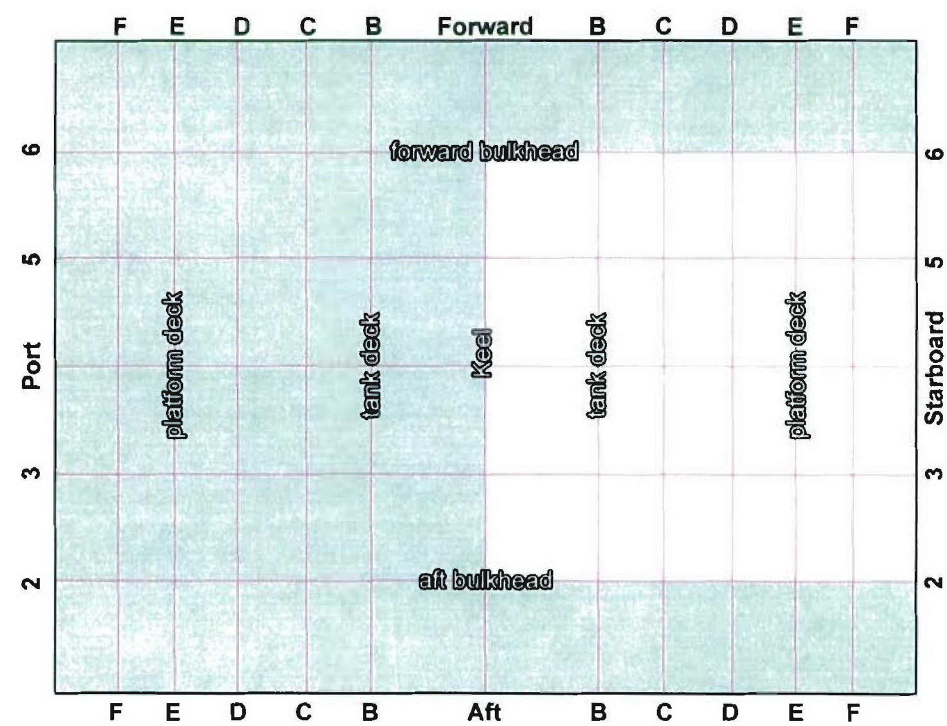

Figure 4. Identification of the Hull Stiffener Pattern

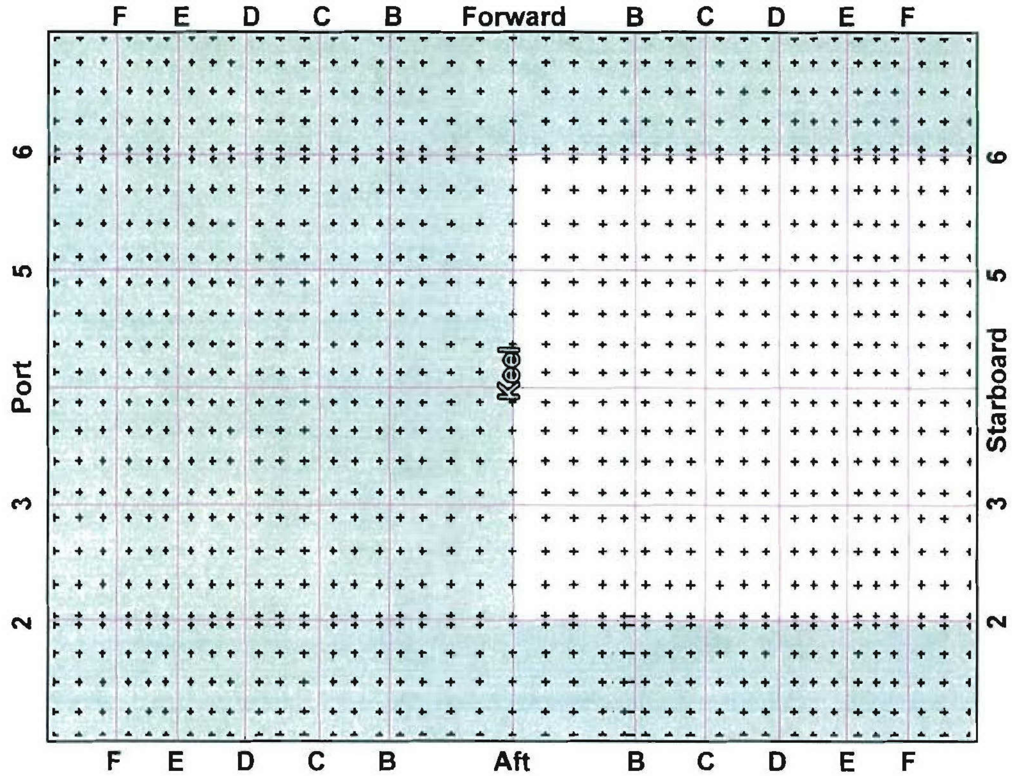

Figure 5. SIDER Test Points Shown by Crosses

Accelerometer Locations

Most SIDER tests use four accelerometers, arranged on an almost symmetrical pattern. However, the symmetry is deliberately broken so that the accelerometer locations are partly randomized. For this study, four accelerometers were used for the SIDER calculations. In addition, the opportunity was taken to acquire additional data for SIDER development. Data for this purpose was taken using a fifth accelerometer which was placed on the top deck. The data from this 5th accelerometer were not used for the results given in this report.

The locations of the four primary accelerometers are shown in Table 2. The accuracy of the table is estimated at ±1".

Table 2. Accelerometers Locations

Accelerometer	Sensitivity (mV/g)	Serial No.	Analyzer channel	X (inch)	Y (inch)
A (port, fwd)	99.1	73281	2	-70.0	76.0
B (port, aft)	102.0	48917	3	-155.5	-76.0
C (stbd, fwd)	101.9	73283	4	175.5	37.5
D (stbd, aft)	102.4	73279	5	101.0	-76.0

Data Quality

On site, the data quality was primarily assessed by observation of the individual coherence functions. When the coherence was atypically poor, the data were rejected and the measurement was repeated until either the coherence improved, or it was assessed that the low coherence was a structural issue rather than a test issue. After the fact, the data quality was assessed by the average coherence calculated for all retained measurements. Figure 6 shows the average coherence for the various trials. Note that the coherence axis is expanded, and only shows the range 80-100%. We would normally consider a high quality data set to have an average coherence in excess of 90%, and preferably more than 95%.

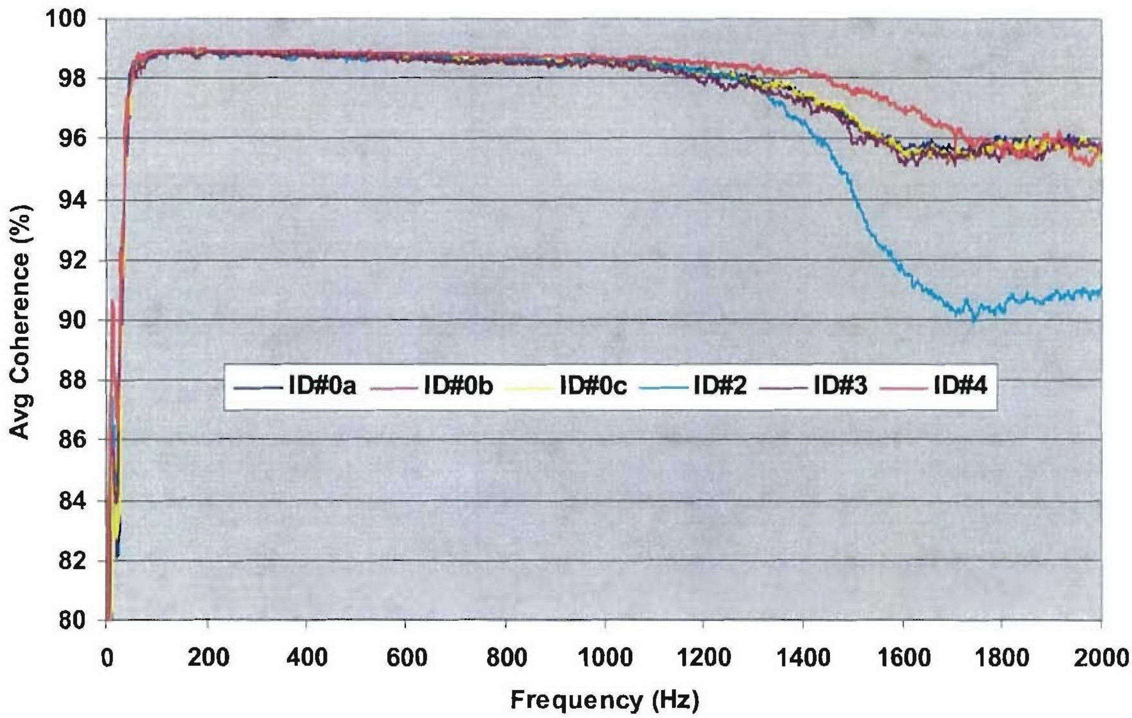

Figure 6. Average Coherence

The average coherence for all three baseline tests (ID#0a, ID#0b and ID#0c) and the data acquired after the third UNDEX (ID#3) are almost identical. For SIDER Test ID#2 (post UNDEX 2), the reduction in coherence above about 1400 Hz is directly attributable to the test environment. The hull was tested outside at Olpenitz and the wind was gusting. During SIDER testing each test point is impacted twice, and the resulting data are frequency averaged. The wind made it difficult to maintain the normal high level of repeatability typically achieved with the impulse excitation, resulting in a slightly reduced high frequency average coherence.

It is interesting to note that the average coherence for SIDER Test ID#4 (post 4th UNDEX) is the highest of all tests, showing that an increase in structural damage is not necessarily reflected in lower quality vibration data. The high coherence observed for this test is attributable to the test conditions. Both testers were well rested. Unlike some of the earlier tests, there was no sense of urgency and the weather was almost perfect – warm, overcast and calm.

The average coherence functions for all SIDER tests are above 98% for the approximate frequency range 125 to 1000 Hz. Therefore, this frequency range was selected for the SIDER calculations.

SIDER Results

As described previously, based on our standard procedures and a careful inspection of the average coherence functions, the SIDER analyses for this structure were conducted from 125 to 1000 Hz, this being the frequency range where the average coherence was above 98%.

Explanation of the SIDER Figures

The keel is in the middle of the graph and runs top-to-bottom in each figure. The left of the picture is the port side of the hull and the right side is the starboard side. Forward is at the top of the figure and aft is at the bottom. The locations of the stiffeners are identified with letters and numbers at the top, bottom and sides of the plots. These letter and number identifiers are the ones established by NSWC and WTD for all documentation associated with this program. The center of each stiffener is marked with a magenta line.

A complete SIDER calculation is acomplished in two stages. The first stage is to conduct a SIDER analysis using lines of data in the fore/aft direction and the second stage is a SIDER analysis using athwartships (port/starboard) lines. The results are shown as a pair of figures.

Single-Analysis SIDER Plots

Contour plots showing the results of a single-SIDER analysis use a red color fill. The graphs are auto-scaled to fit the maximum value on each plot. Solid red indicates that the single SIDER analysis has identified variations in structural stiffness, whereas white indicates uniformity of stiffness. For a structure with nonhomogeneous structural properties, i.e., a structure with ribs and stiffeners, the pattern shown on a single-SIDER contour plot is primarily related to structural features. For a structure with homogenous structural properties, i.e., a monolithic composite laminate or sandwich core structure, the pattern shown on a single-SIDER contour plot is related to material anomalies or defects. In the latter case it, is often damage or manufacturing defects which cause changes in the structural stiffness.

For the corvette hull structure, the single SIDER analysis results are archived and used as a baseline for comparison with data taken at a later stage. The difference between these later measurements and the baseline can be used to assess structural change.

A single SIDER baseline can be used for manufacturing quality control of similar test articles, and in some previous tests a single SIDER analysis has identified areas of poor manufacture and/or damage. The single SIDER is most effective at locating damage if a structure is uniform and homogenous, or has strong nominal symmetry. The single SIDER assessment of manufacturing quality and/or damage caused to this hull section during shipping and earlier testing at Lehigh University will be the subject of a separate report, and the work is excluded from this report.

SIDER Difference Contour Plots

The difference plots show the difference in SIDER values compared to the baseline SIDER values. The change in SIDER can be positive or negative, and the contour plots include both positive and negative values. The plots are magnified by a factor of ten when compared to the baseline SIDER results. Positive values are shown red; negative values are shown blue; and values close to zero are shown white.

Baseline SIDER Results

Baseline SIDER Test ID#0a

This test provided the baseline used for all the later difference results. The data were acquired over two days, as shown in Table 1. The structure was quiet during testing, and there is high confidence in the quality of the data. The single SIDER results are shown in Figure 7 and Figure 8.

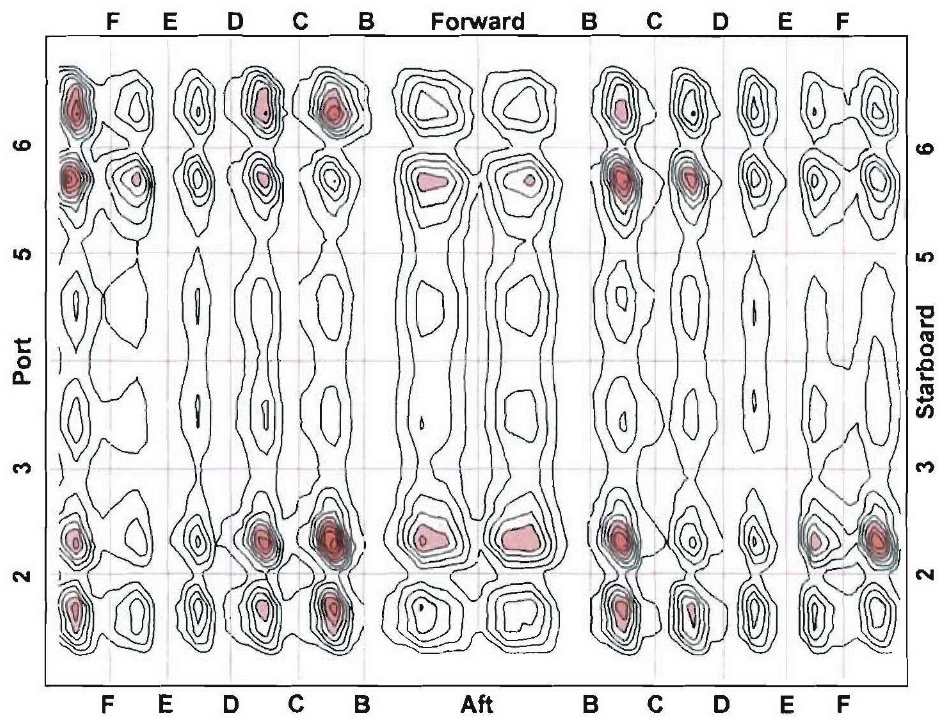

Figure 7. Baseline SIDER ID#0a – Fore/Aft Analysis

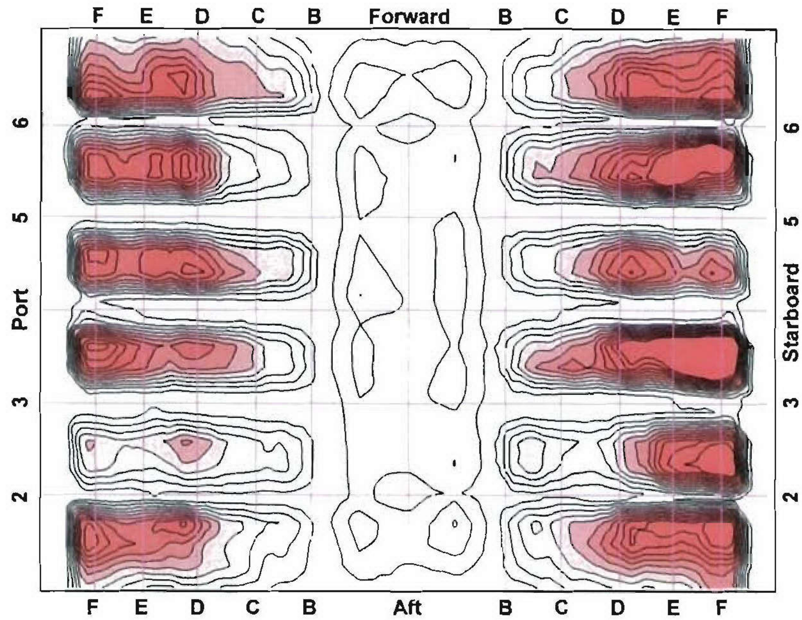

Figure 8. Baseline SIDER ID#0a –Athwartships Analysis

Observations for ID#0a

The fore/aft analysis has identified the stiffness changes associated with the stiffener pattern. It has also identified that the bulkheads (athwart ships at stiffener locations 2 and 6) generate more stiffness variation than the other stiffeners.

The athwartships analysis has identified that the stiffness in the bays between the stiffeners continuously changed from the keel to the upper deck. This is consistent with the manufacture, where there are progressive ply drops from the keel to the upper deck. Figure 8 shows that there are structural differences in the hull. Comparing the port and starboard SIDER results, there is a definite lack of symmetry in the regions between the bays. This is especially evident in the region between the aft bulkhead 2 and stiffener 3.

Repeat Baseline SIDER Test ID#0b

In order to assess susceptibility of the data acquisition to structural noise and also to assess the overall repeatability of the SIDER process, the baseline test was repeated as SIDER ID#0b. During data acquisition several people were moving about inside the hull while they checked other instrumentation associated with the UNDEX tests. These people tried to be reasonably quiet, in order to prevent unwanted vibration of the hull during SIDER data acquisition. However they did move and their changing mass loading may have affected the dynamic characteristics of the hull.

The single-SIDER plots for baseline SIDER ID#0b are not shown in this report since they look almost identical to the plots for SIDER ID#0a.

Figure 9 and Figure 10 show the difference between the original SIDER (ID#0a) and the repeat baseline (SIDER ID#0b). The plots are to the same scale as the ID#0a single-SIDER plots shown in Figure 7 and Figure 8. Overall, the figures demonstrate repeatability and little susceptibility to the structural mass loading and noise issues discussed above. However, there was a measurable difference at an area on the port side between longitudinal stiffeners F and E and near bulkhead frame 2 as seen by the only red region on the figures.

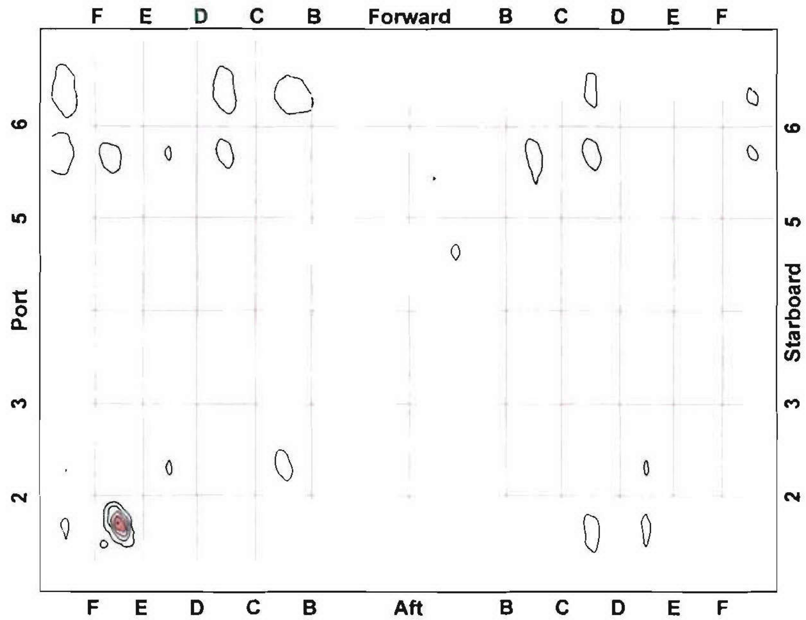

Figure 9. Repeatability (ID#0b-ID#0a) Fore/Aft

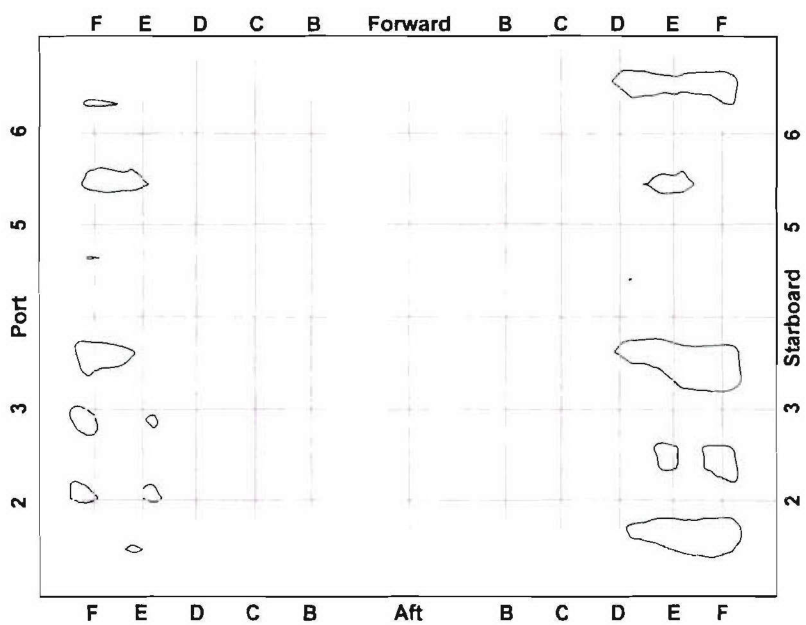

Figure 10. Repeatability (ID#0b-ID#0a) Athwartships

Baseline Path SIDER Test ID#0c

It was decided to retest the area coincident where there was a significant change in the SIDER difference analysis. Because of the concerns with the instrumentation on the first day of data acquisition as described earlier in this report, it was decided to slightly extend the patch to the area shown as the green region in Figure 11. This subset of data replaced matching data in ID#0b, and was cumulatively called ID#0c.

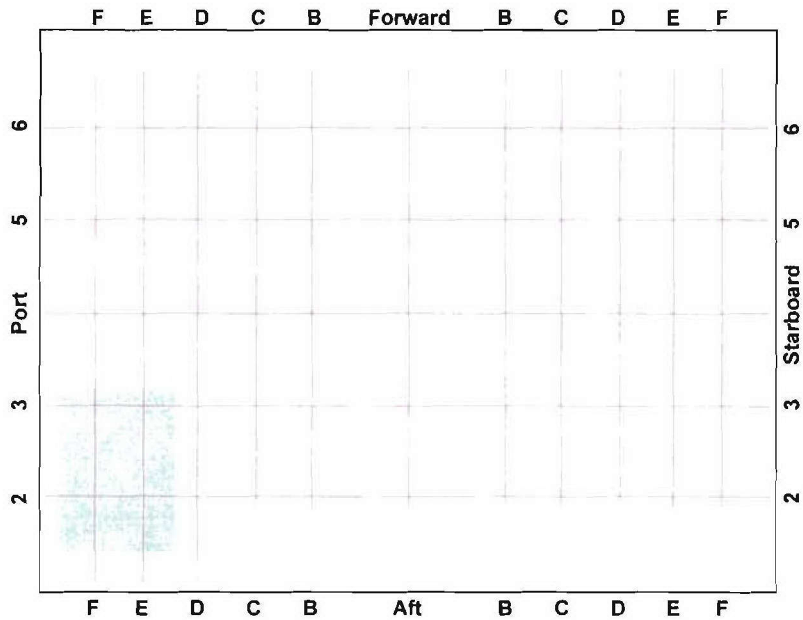

Figure 11. SIDER ID#0c – Green Showing the Data Patch Area

With the patch applied, the difference between this last baseline set ID#0c and the original baseline ID#0a is shown in Figure 12 and Figure 13. The figures show that there is almost no difference between the baseline ID#0a and repeat baseline ID#0c. For the remainder of the results shown here, ID#0a was arbitrarily selected as the true baseline.

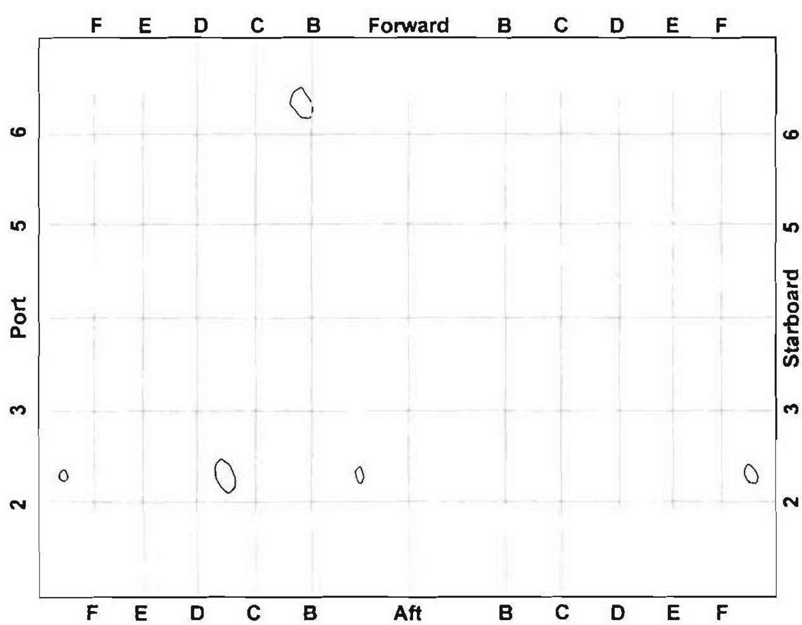

Figure 12. Repeatability (ID#0c-ID#0a) Fore/Aft

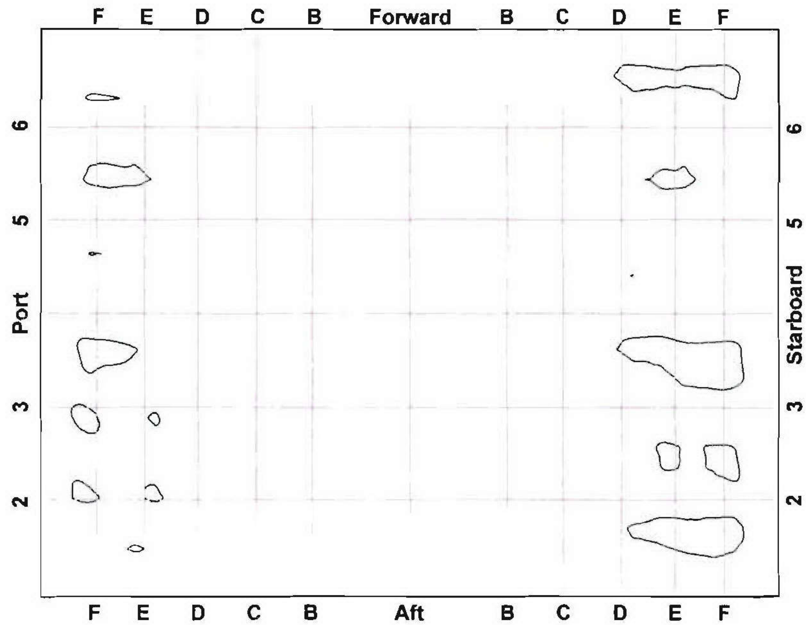

Figure 13. Repeatability (ID#0c-ID#0a) Athwartships

SIDER Assessment of UNDEX-Caused Structural Changes

All of the SIDER difference plots shown in this section have the same format, described here.

- The SIDER difference results are all calculated as (post-UNDEX values) minus (baseline). The scaling used in these difference plots is a ten-times magnification of the scales used for the baseline plots.
- The centerlines of the stiffeners are shown as magenta lines, and the area that was not subject to VT/UT inspection is shown with a green background (i.e., the VT/UT-inspected area has a white background).
- A lone area of RED indicates an increasing variability of stiffness. This is typically associated with a relatively uniform area of structure which is seeing localized structural degradation.
- A lone area of BLUE indicates an area of the structure which is seeing a *reduced variability of stiffness.* This is typically associated with relaxation of localized stiffening, e.g., tabbing or frames.
- An area of RED adjacent to an area of BLUE typically indicates that there is a structural change *between the two colored areas*, rather than directly at the locations indicated by either color.

The main concept of SIDER is that it can be used to rapidly interrogate large surface areas. The areas where SIDER locates features should then be inspected with a more detailed tool such as UT, thermography, laser shearography, etc. It is important to remember that SIDER only locates problems that have structural significance, i.e., where the stiffness pattern of the structure has changed. It will not locate features that do not significantly affect the structural stiffness.

The plots are shown in sets as follows:

- The next three pages contain two SIDER difference plots per page - Figure 14 to Figure 19 (after the 2nd, 3rd and 4th UNDEX, respectively). The first plot on each page gives the results for the fore/aft analysis, and the second plot gives the results for the athwartships analysis. The results are presented in these sections without discussion.
- Following Figure 14 to Figure 19, the above results are repeated, but with significant features identified and annotated. First, the three plots for the fore/aft analysis (one for each UNDEX) are shown and discussed –Figure 20 through Figure 22. Second, the three athwartships results are shown and discussed – Figure 23 through Figure 25.

SIDER Difference Plot after 2nd UNDEX

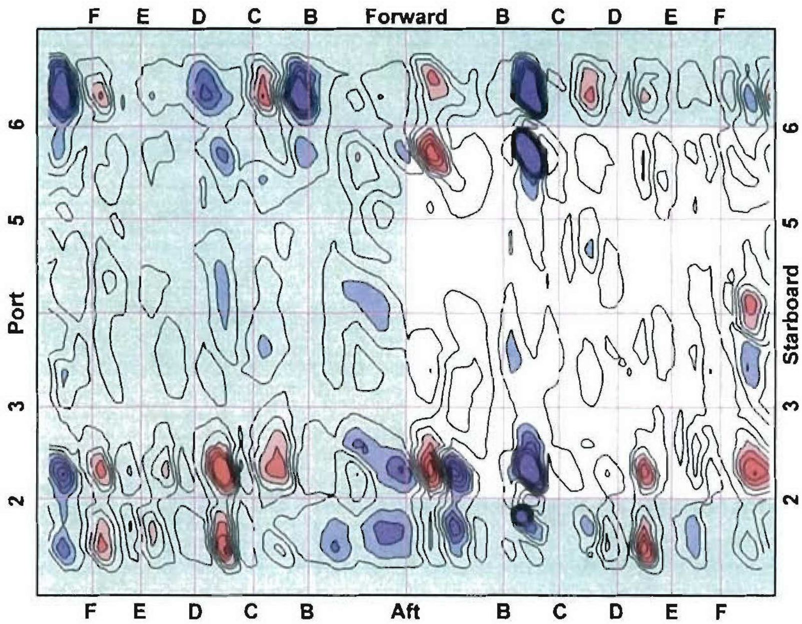

Figure 14. SIDER Difference (ID#2-ID#0a) Fore/Aft

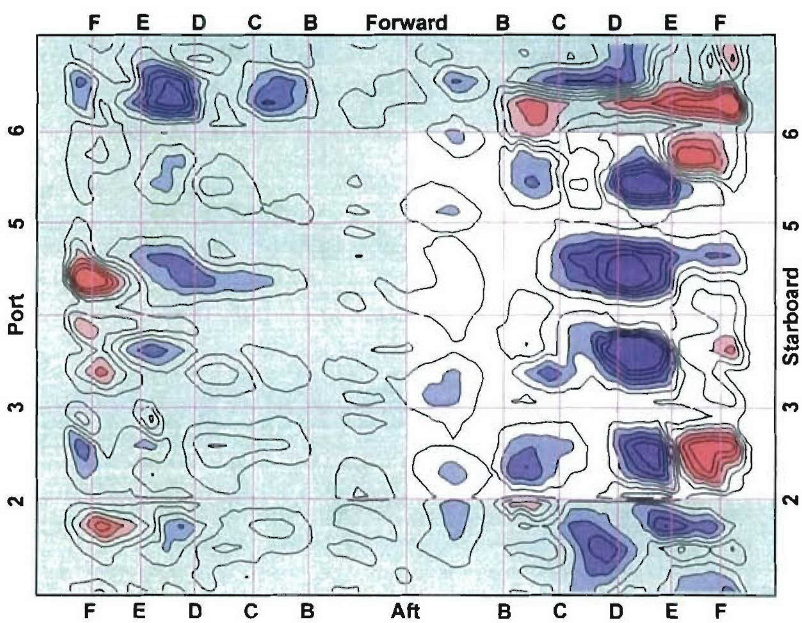

Figure 15. SIDER Difference (ID#2-ID#0a) Athwartships

Sider Difference Plot after 3rd UNDEX

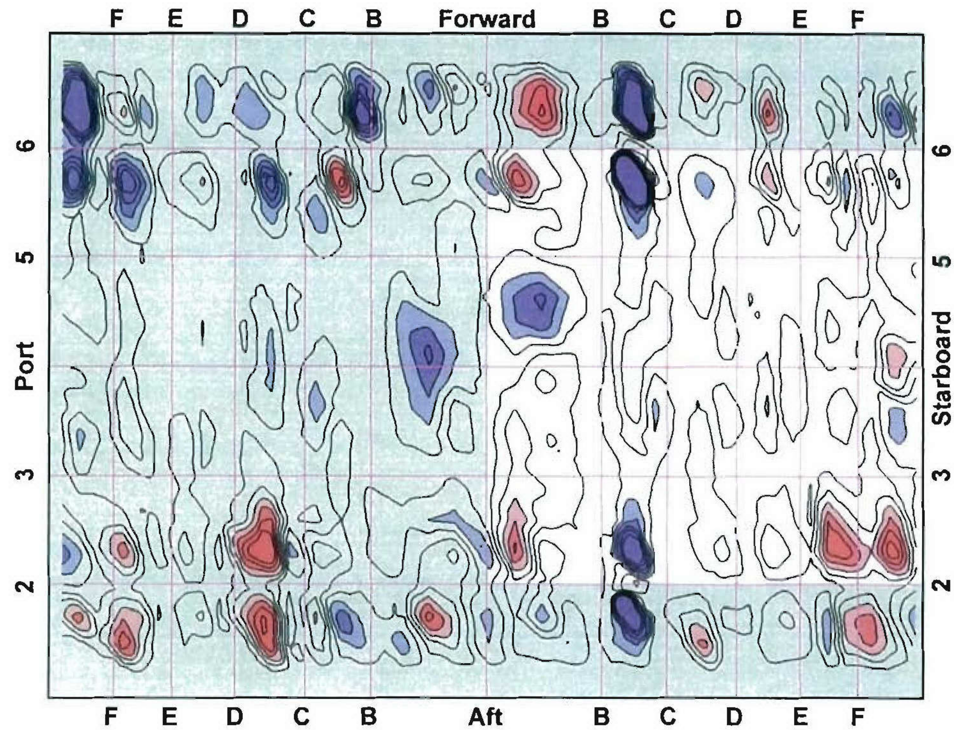

Figure 16. SIDER Difference (ID#3-ID#0a) Fore/Aft

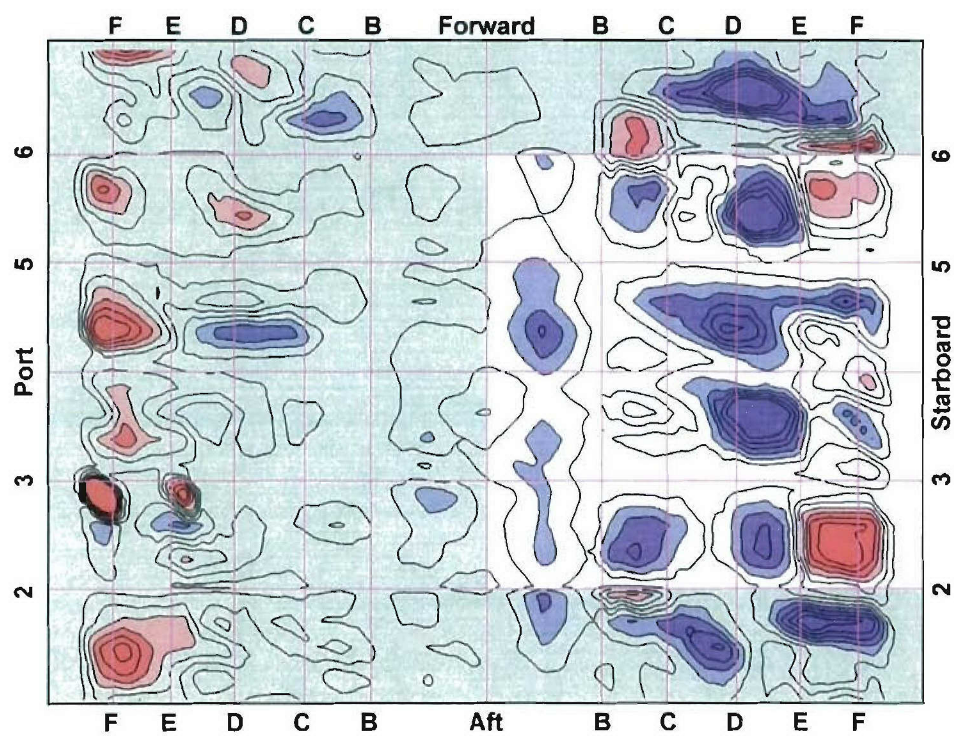

Figure 17. SIDER Difference (ID#3-ID#0a) Athwartships

Sider Difference Plot after 4th UNDEX

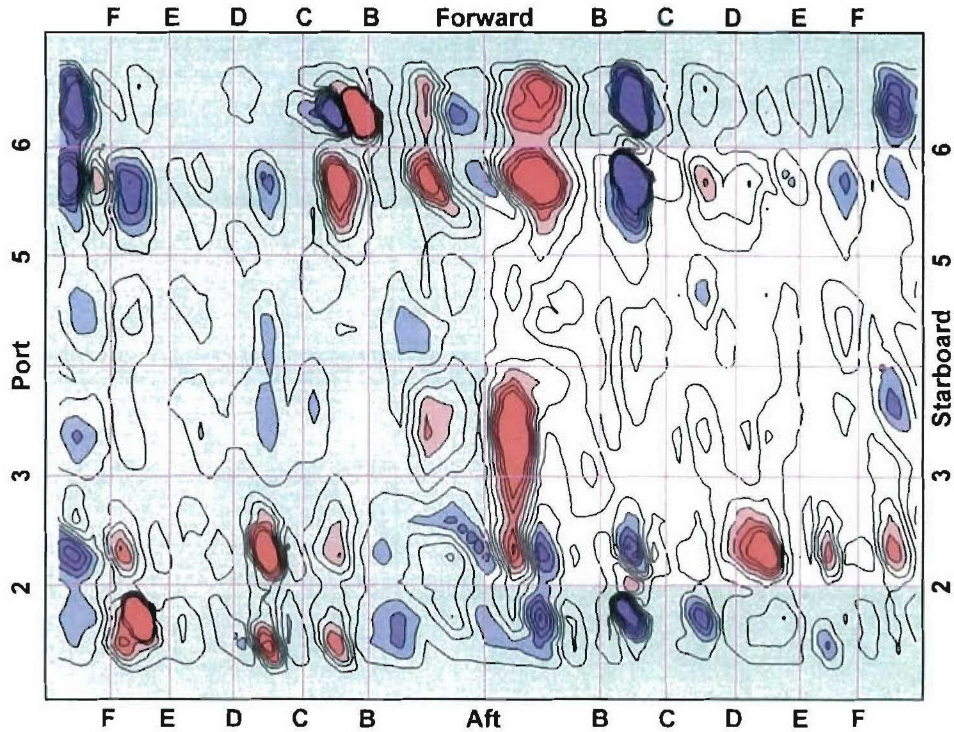

Figure 18. SIDER Difference (ID#4-ID#0a) Fore/Aft

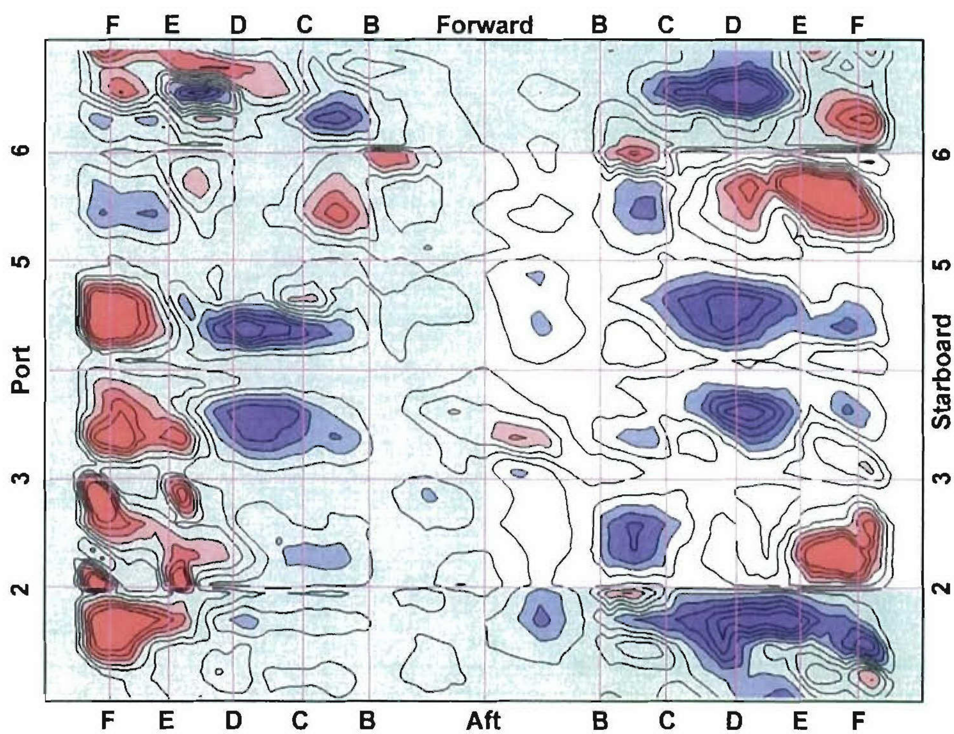

Figure 19. SIDER Difference (ID#4-ID#0a) Athwartships

Discussion of SIDER Difference Results – Fore/Aft Analysis

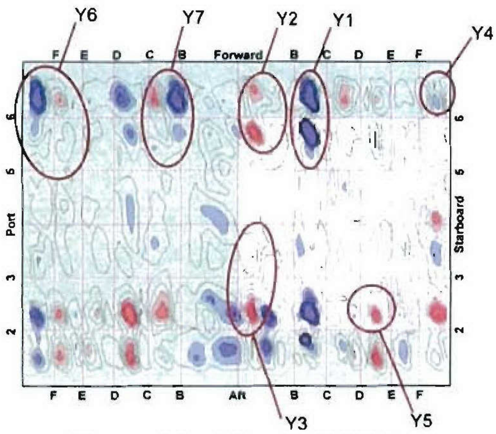

Figure 20. After UNDEX 2

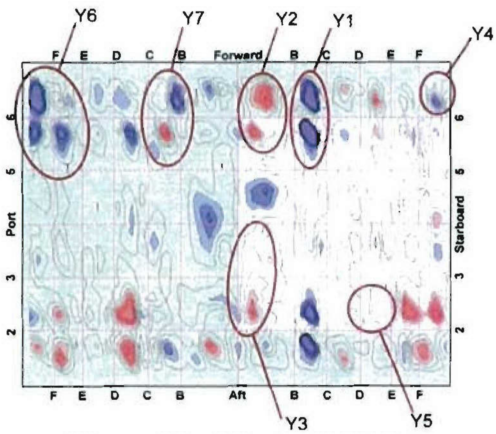

Figure 21. After UNDEX 3

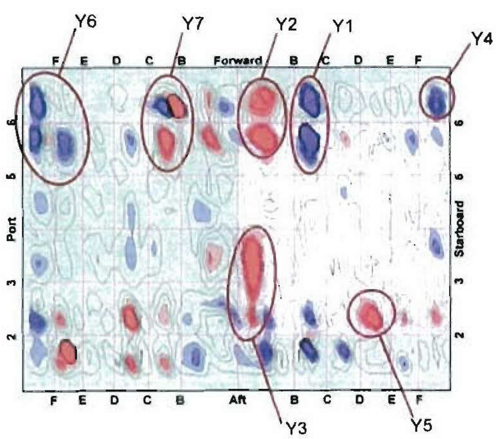

Figure 22. After UNDEX 4

Feature Y1

UNDEX 1 or 2 caused some structural change, probably a relaxation of tabbing. There was no further development with later UNDEX.

Feature Y2

Steady progress of localized structural change with increasing UNDEX. This is the location where the external ply buildup failed after UNDEX 3; see Figure 23.

Feature Y3

On the starboard side of the keel, aft of the centerline. Small early indication after UNDEX 2 which developed significantly after UNDEX 4. Feature most prominent near the keel/aft bulkhead intersection.

Feature Y4

Early minor detection after UNDEX 3, with more development during UNDEX 4.

Feature Y5

Early detection after UNDEX 2, with rapid progress during UNDEX 4.

Feature Y6

Some early indications of change that developed during UNDEX 3.

Feature Y7

Early indications after UNDEX 2 with significant change during UNDEX 4.

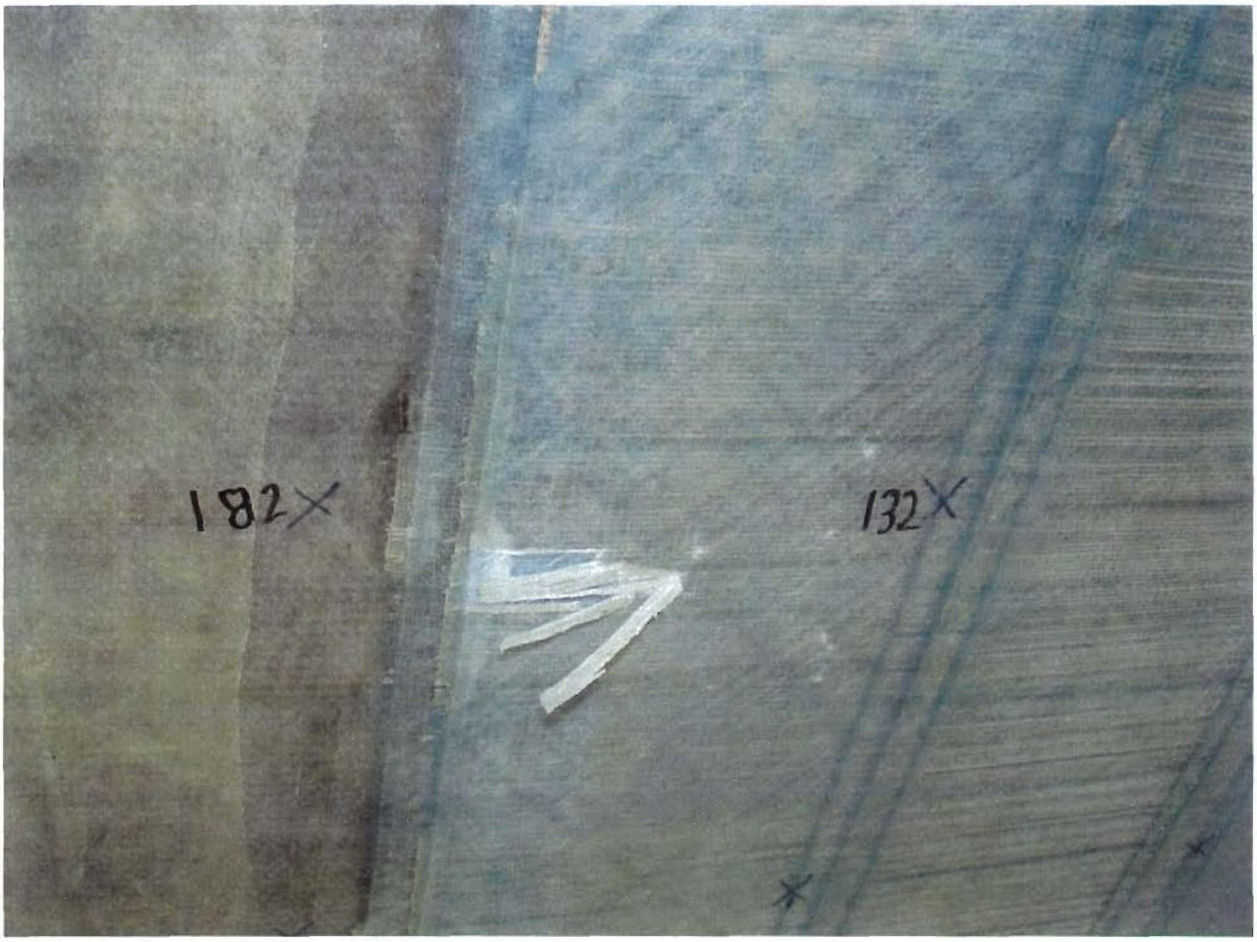

Figure 23. External Ply Buildup Failure after UNDEX 3

Discussion of SIDER Difference Results – Athwartships Analysis

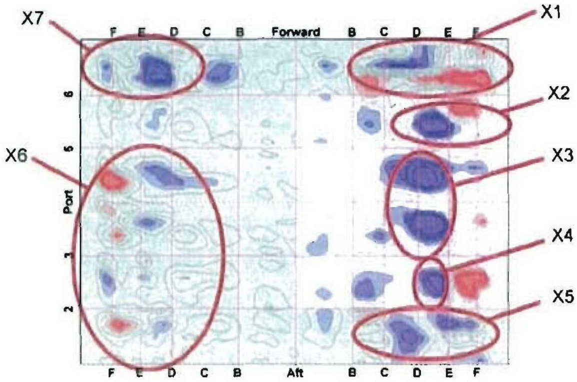

Figure 24. After UNDEX 2

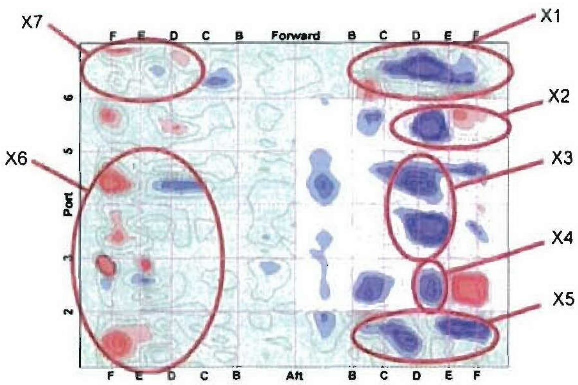

Figure 25. After UNDEX 3

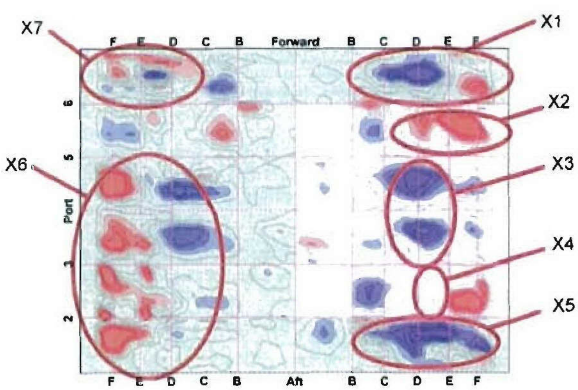

Figure 26. After UNDEX 4

Feature X1

Extensive indications on the buildup forward of the bulkhead. This feature spreads toward the bulkhead during later UNDEX.

Feature X2

After UNDEX2 this feature showed blue, suggesting relaxation of tabbing. After UNDEX 4 this feature turned red, indicating a significant structural change.

Feature X3

Large blue areas that did not change with later UNDEX.

Feature X4

UNDEX2 caused this blue area to appear. After UNDEX 4 this area disappeared. The change from blue toward red (stopping at white) is indicative of a significant structural change.

Feature X5

A rapidly developing area indicative of tabbing relaxation aft of the aft bulkhead.

Feature X6

This large port side area shows steady development with UNDEX. It is interesting to note that the port side is predominantly red, whereas the starboard side is predominantly blue. This suggests the two sides saw different types of damage.

Feature X7

A strong feature on the ply buildup starboard side, forward of the forward bulkhead, that developed after UNDEX 4.

Comparison of SIDER and VT/UT Findings

This section of the report compares the VT/UT and SIDER findings. The discussion and plots are only presented for the final test after the 4th UNDEX shot. Kevin Clear and Jeff Zook, NSWCCD, Code 62, Philadelphia conducted the VT/UT testing in Germany. Discussion with the VT/UT team about their testing methodology suggested the following:

- The structure was primarily VT. Where VT suggested there might have been a problem, it was inspected with UT. Tabbing was checked with UT irrespective of VT indications.
- A hockey puck (HP) probe with a relatively large head size was used to quickly scan the tabbing from the inside of the hull. Its large size meant it could not be used on curved surfaces, or for the identification of small features. Coupling on the inside of the hull was difficult because of surface roughness.
- A smaller ZIP probe was used to inspect the curved surface of the tabbing where it transitioned from the hull to the stiffener (the fillet region over the filler material) and to discriminate features identified with the HP.
- A Fast 3 (F3) probe was used from the outside of the hull to inspect the filler material between the tabbing and stiffener. For earlier testing, the VT/UT team were unable to obtain the necessary reflections from the fillet region of the tabbing material. Later testing (after the 3rd UNDEX and later) used a different angled transducer holder which could identify suitable reflections.
- The VT/UT team stated that they could not test directly behind any of the stiffeners or bulkheads because they did not have a suitable calibration block.
- Water was used as the coupling agent, but this was not totally successful. The VT/UT team stated gel would have made a better coupling agent, but they only had a small quantity of gel with them, and there was not enough available for local purchase. Also, they did not want to use gel because of the subsequent cleanup that would have been required.

During SIDER testing after the 4th UNDEX, the following VT/UT-related observations were noted:

- At least one VT/UT-identified damage feature was exactly coincident with an external waterproofing patch. The marked region exactly matched the non-square shape of the partially peeled patch. It seems unlikely, but not impossible, that damage would coincide exactly with the patch. Verification of the VT/UT results was beyond the scope of this SIDER project, and while the anomaly is noted here, the SIDER team did not attempt to verify the remainder of the VT/UT findings.
- Onsite, the VT/UT team demonstrated the use of their calibration blocks. It is assumed that they were aware that the skin thickness varied with distance from the keel. If not, some of the features identified with the Fast 3 probe may need additional verification.

Figure 27 shows the areas where the VT/UT inspection identified features after the 4th UNDEX. Fast 3 (F3) indications are shown in blue; hockey puck (HP) indications are shown in green; and indications identified by both F3 and HP are shown in red. The figure also repeats the

SIDER regions identified where there was cause for concern, i.e., those regions where SIDER suggests a more detailed inspection is warranted. ZIP findings are presented in Figure 28.

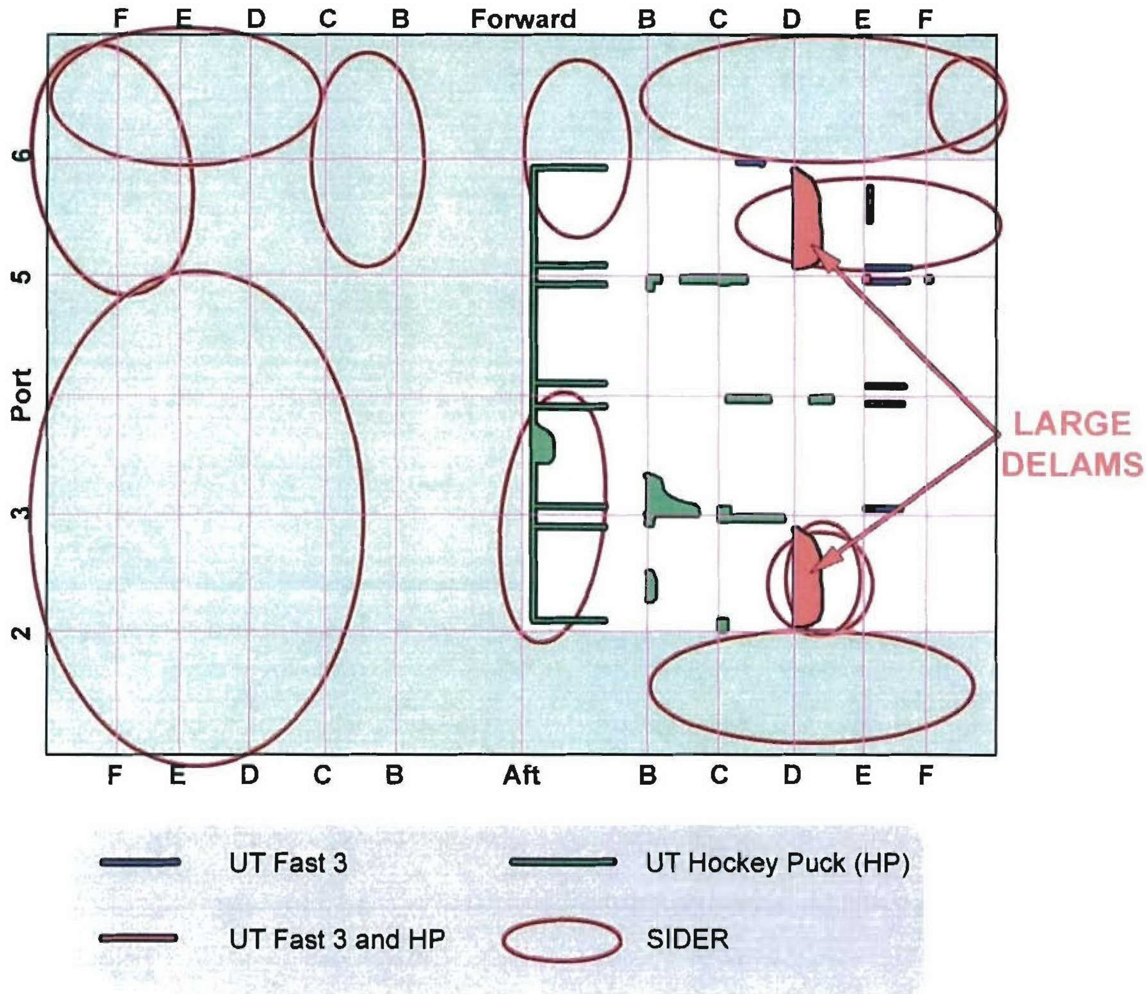

Figure 27. VT/UT F3 and HP Identified Regions Compared with Areas of Concern Identified by SIDER

The following observations are noted:

- VT/UT only tested about one-half of the starboard side. SIDER found several areas of concern in other areas that were not VT/UT tested.
- There were only two significant delaminations. Both were inside areas identified by SIDER as places of concern.

SIDER did not identify all of the areas located by VT/UT. There are several reasons for this, including:

- SIDER is designed to screen an entire structure and then use its findings to direct more detailed inspection methods. As such, it locates the most significant areas, and not necessarily all damage sites. SIDER achieved this aim, since, within the area that was VT/UT inspected, all SIDER identified regions had VT/UT indications of damage.

- To some extent SIDER ranks the features. The VT/UT results made available to the SIDER team only presented findings as "something or nothing". Therefore in this report it is not possible to state which VT/UT features are structurally of most significance. The identification "LARGE DELAMS" was added by the SIDER team, and was not part of the inspection information that the VT/UT team provided to the SIDER team.

Figure 28 shows the VT/UT ZIP probe results compared with the combined athwartships and fore/aft SIDER difference results. While many of the SIDER features are coincident with ZIP findings, the ZIP results are not ranked for degree of severity and this precludes making a meaningful comparison. Other than presenting the results as-is, further comparison and discussion is neither warranted nor made in this report. Note that the VT/UT tested area for this probe was slightly smaller than the area VT/UT tested with the other probes.

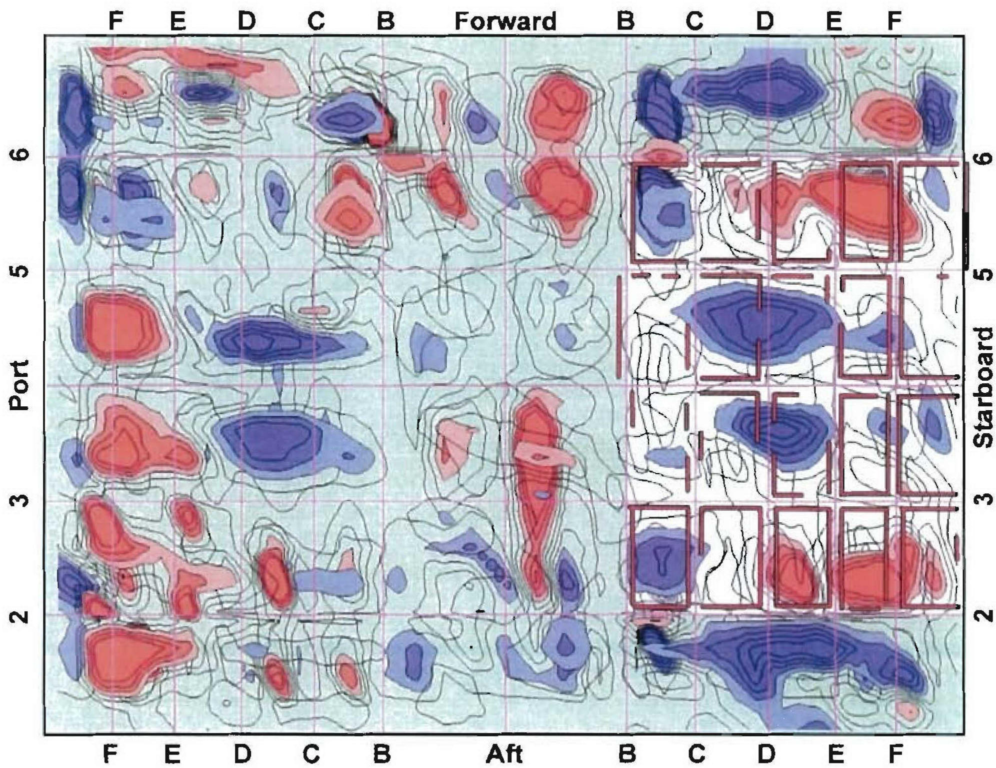

Figure 28. VT/UT Indications of Radius Problems Identified with ZIP Probe Compared with the Combined Athwartships and Fore/Aft SIDER Difference Results

Conclusions

SIDER quickly established plots of potential damaged areas. For example, after the second UNDEX, the hull section was repositioned on the jetty at Olpenitz at approximately 1700. By 2230 that night the complete SIDER results for the entire hull section were being presented to the project management in the hotel at Eckernforde. This 5-½ hour period included attaching transducers, running cables, setting up the analyzer, data capture, removing cables and transducers, data reduction and a drive of about half an hour.

Within the area that was VT/UT inspected, all SIDER-identified areas of concern showed VT/UT indications of damage.

Some VT/UT features were not revealed by SIDER. This is acceptable, since SIDER is designed to quantify and locate the main areas of structural concern. Conceptually, VT/UT will then inspect those areas first, and only if features are found will VT/UT continue to inspect larger areas.

It is not known if the VT/UT features identified within the test area were of structural significance or not. In making this statement it is recalled that the baseline VT/UT measured by NSWCCD, Code 62, Philadelphia at Lehigh University in 2002 identified several delaminations that were reported[1] to be "major". None of these areas significantly changed during the series of UNDEX tests, whereas previously 'clean' areas suffered damage.

This project has demonstrated the feasibility of using SIDER as a pre-inspection procedure for large area structures as a precursor to using other more detailed, but time consuming, methods.

Recommendations

The following recommendations for further work are made:

The possibility of using a single, remote transducer for SIDER should be investigated.

- For future builds, embedded transducers will speed up the SIDER process, and may also lead to automation and real-time health monitoring.
- The VT/UT raw signal data obtained for this project should be reexamined to verify all reported features match to actual damage.
- The Fast 3 data should be examined to verify that it correctly took into account the variable shell thickness. Alternatively, if this was done during the examinations, the appropriate calibrations and inspection efforts should be documented and certified.

[1] Meeting at NAVSEA 05M on Thursday May 12, 2005 to discuss SIDER. In attendance, Ratcliffe and Crane (SIDER), Kok (NAVSEA 05ME), Goldring (NAVSEA-05M), Bandos (NSWCCD, Code 62), Lipetzky (NSWC-CD, Code 61), and DeNale (NSWCCD, Code 61).

- Based on the verbal reports by the VT/UT team to the SIDER team, and the amount of time it took them to perform the VT/UT inspection, this structure was clearly a difficult one to VT/UT inspect. The damage that was detected by the UT ZIP probe after the 4th UNDEX was extensive and apparently reasonably uniform throughout the inspected area. The VT/UT team indicated that these results showed that almost all the filler-to-skin bond had failed at the same time and to the same extent during this UNDEX. To verify this unusual finding, it would be instructive to compare the raw signal data from the earlier UT ZIP testing with the results of the post 4th UNDEX inspection to confirm that the features were indeed not present in the earlier tests. This would ensure that these latter results were not merely the product of improved signal interpretation and experience with the hull section.

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